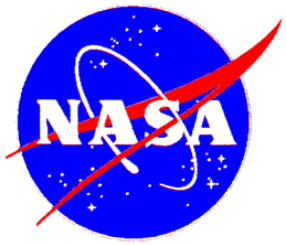

Three-Dimensional Air Quality System (3DAQS)
Final Benchmark Report

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NASA Applied Sciences Program
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Introduction

The NASA Applied Sciences Program supports applied science research, applications, and decision support activities that supply foundational applied knowledge and enable practical applications of Earth science products and knowledge in partnership with end-user organizations. The Program serves as a bridge between the data and knowledge generated by NASA Earth science research programs and the information needs and decision-making of government agencies, companies, and other organizations. The Applied Sciences Program focuses on eight applications areas: Agriculture, Air Quality, Climate, Ecological Forecasting, Natural Disasters, Public Health, Water Resources, and Weather.

The Applied Sciences Program selected the 3DAQS: Three Dimensional Air Quality System project for funding as part of the 2004 Decisions Cooperative Agreement Notice (CAN). 3DAQS focused on the application of aerosol-related NASA Earth Science Data in key Decision Support Systems (DSS) used by the U.S. Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA). The 3DAQS project utilized aerosol data from MODIS, OMI, GOES, CALIPSO, AERONET, AIRS, MPLNET, REALM and ground-based UMBC resources. As such, it represents a significant integration of satellite systems into existing decision support systems. The 3DAQS project team included a core team of experts in atmospheric science and air quality policy, including co-investigators from NASA Langley Research Center (LaRC), NASA Goddard Space Flight Center (GSFC), the University of Maryland, Baltimore County (UMBC), EPA, NOAA, the Centers for Disease Control (CDC), and Battelle. UMBC led management of the proposal.

Project Accomplishments and Benchmarking

Running from 2005-2010, the 3DAQS project has helped make NASA satellite data more accessible and useful for the air quality community. Major accomplishments of 3DAQS include re-gridding and matching satellite data to ground-based monitors, and making these satellite datasets available through EPA's RSIG, transitioning the IDEA (Infusing satellite Data for Environmental Applications) website (http://www.star.nesdis.noaa.gov/smcd/spb/aq/) an operational environment at NOAA, making several significant improvements to IDEA, training the air quality community on use of satellite data for air quality analysis, publishing 11 journal articles (Delgado et al., 2010; Engel-Cox et al., 2005a, 2005b, 2006; Hoff et al., 2005, 2009a, 2009b; Kondragunta et al., 2008; Weber et al., 2010; Zhang et al. 2008, 2009), and making 40 direct or leveraged conference presentations (http://alg.umbc.edu/3d-aqs/presentations.html).

Five performance metrics are used to benchmark the results of the 3DAQS project. The baselines of these metrics were established at the beginning of the project in an Initial Benchmark Report (http://alg.umbc.edu/3d-aqs/doc/Benchmark_Report.pdf). Overall, 3DAQS has been very successful. Results of the benchmarking analysis suggest that 3DAQS has made satellite data more accessible to the air quality community through IDEA and the U.S. Air Quality weblog (the "Smog Blog," http://alg.umbc.edu/usaq/). Several research groups have contacted the 3DAQS team directly regarding the re-gridded and matched-to-monitors satellite

datasets that were developed as part of the project, demonstrating the utility of this task. These datasets are also available to the community at large, as described in the Metric 4 section. The end result is that 3DAQS products, particularly the Smog Blog and IDEA, have become essential components of the air quality community. The adoption of 3DAQS data and products by EPA and NOAA is providing a sustainable future for the work carried out by the 3DAQS project. To this end, the 2007 letter of commitment from NOAA NESDIS to the Applied Sciences Program is attached as Appendix C, as described in the Metric 3 section.

Metric 1: End User Group Input

Throughout the course of 3DAQS, the End User Group has provided advice and feedback on all aspects of the project. The 3DAQS End User Group consists of 25 state and local air quality forecasters, federal air quality analysts, and university researchers. Table 1 lists the members of the 3DAQS End User Group, including their affiliations and major application areas. During the course of the project, the 3DAQS team had five teleconferences with the End User Group to obtain their input on tasks and provide updates on project status. Table 2 is a summary of the End User Group teleconferences, including dates and main topics.

To benchmark project performance, the 3DAQS team surveyed the End User Group at the beginning and end of the project. The initial End User Group survey included 16 general questions on the use of satellite data, temporal and spatial data resolutions, data format and delivery, and visualization preferences. The final End User Group survey focused on determination of whether the 3DAQS project impacted the way End Users use satellite data in their work.

A complete record of the final End User Group survey results is listed in Appendix A. The survey contained 12 questions, which were mostly multiple-choice, with a few questions that required a written response. 10 of the most active End User Group members provided answers to the survey. The majority of these respondents – 70% – work for state governments, while 20% work for the federal government, and 10% work for universities. 50% of the respondents use satellite data daily, with the remainder split about evenly between using satellite data weekly, monthly, and only during major pollution events. The most popular applications of satellite data indicated by End Users who responded to the survey are air quality forecasting (70%) and retrospective event analysis (80%).

Almost all of the respondents to the survey use fire/smoke products and MODIS/GASP AOD routinely in their work, while many also use MODIS true color imagery, OMI NO_2/SO_2, CALIPSO, and NAAPS aerosol forecasts. An air quality forecaster End User indicated that "overall, 3DAQS has been most helpful with smoke issues," since fires can be difficult for forecasters to monitor on a national level. 70% of the End User respondents rely on prepared satellite imagery available on the internet; only 10% download data for their specific applications, which underscores the importance of 3DAQS products such as IDEA and the Smog Blog that provide air quality satellite images. In fact, 90% of survey respondents indicated that they use the Smog Blog for their work, and 70% said they use IDEA. In the initial benchmarking, IDEA was mature but only included MODIS Terra. Between the initial and final benchmarking surveys, there has been a 7% increase in End Users who say they use IDEA for their work. This increase may be due to the new features added to IDEA during the course of

3DAQS. In contrast, the Smog Blog was less well known initially and experienced a 37% increase in usage over the duration of the 3DAQS project.

NASA 3DAQS End User Group Members			
Name	**Organization**	**Phone**	**Email**
EPA			
Bryan Bloomer	National Center for Environmental Research, USEPA	(202) 343-9078	Bloomer.Bryan@epa.gov
Terry Keating	Office of Air and Radiation, USEPA Headquarters	(202) 564-1174	keating.terry@epa.gov
Tesh Rao	Office of Air and Radiation, USEPA Headquarters	(919) 541-1173	rao.venkatesh@epa.gov
Rich Scheffe	Office of Air and Radiation, USEPA Headquarters	919-541-4650	Scheffe.Rich@epa.gov
Phil Dickerson	Office of Air and Radiation, USEPA Headquarters	919-541-4814	Dickerson.Phil@epa.gov
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Carol Bohnenkamp	USEPA Region 9	(415) 947-4130	bohnenkamp.carol@epa.gov
FORECASTERS			
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Ajith Kaduwela	California Air Resources Board	(916) 327-3955	akaduwel@arb.ca.gov
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Michael Woodman	Maryland Department of the Environment	(410) 537-3229	mwoodman@mde.state.md.us
ANALYSTS/MODELERS			
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Julie McDill	The Mid-Atlantic Regional Air Management Association	(410) 467-0170	jmcdill@marama.org
Matthew Seybold	National Environmenal Satellite, Data, and Information Service (NESDIS), NOAA	(301) 763-8142 x128	matthew.seybold@noaa.gov
Dale Allen	Department of Atmospheric and Oceanic Sciences, University of Maryland	(301) 405-7629	allen@atmos.umd.edu
Yang Zhang	Air Quality Forecasting Lab, North Carolina State University	(919) 515-9688	yzhang9@ncsu.edu
Tom Moore	Western Regional Air Partnership	(970) 491-8837	mooret@cira.colostate.edu

Table 1. 3DAQS End User Group Members.

One federal government End User commented in the survey, "The IDEA site coupled with the Smog Blog has increased my awareness of [air quality] events and available data on these events that I log and retrieve later when doing retrospective analysis or proposal development." A state air quality forecaster wrote, "The 3DAQS project has enhanced my desire and ability to utilize satellite products in my air quality forecasting. It has exposed me to a broader range of resources to make my forecast. The Smog Blog is very beneficial to me, as I'm able to see (on a national and local scale) the air quality conditions. The satellite and air quality images provided in the Blog are also a great resource." Based on these survey comments from the End Users, as well as in person discussions with End Users, the 3DAQS project has had a positive impact on the way the air quality community utilizes satellite data in their work.

Call	Date	Main Topics
Kick-Off Call	9/26/06	Introduction to the 3DAQS project
		Review of initial End User Group survey
Call #2	4/12/07	AOD algorithms (V4 and 5): data accuracy and attributes
		3D visualization/CALIPSO: introduction and preliminary input
Call #3	10/1/07	Discussion of satellite datasets proposed for inclusion in 3DAQS
		Update on AirQuest: how to access 3DAQS data
		Plans for 3D visualization of 3DAQS data
Call #4	3/7/08	Review of feedback from Call #3 regarding preferred datasets
		Update on AirQuest: how to access 3DAQS data
		Demonstration of new features on IDEA and Smog Blog
		Plans for 3D visualization of 3DAQS data
Final Call	3/2/10	Update on final status of the 3DAQS project
		Update on new features on IDEA
		Preview of final End User Group survey

Table 2. Summary of 3DAQS End User Group Teleconferences.

At the conclusion of 3DAQS, the project team transitioned many of the End User Group members into a new Advisory Group for the NOAA GOES-R Air Quality Proving Ground (AQPG). GOES-R, scheduled for launch in 2015, is the first in the next generation of NOAA geostationary weather satellites, designed to replace the current series of Geostationary Operational Environmental Satellites (GOES). The GOES-R AQPG is an experimental test-bed that NOAA established to prepare the user community for new GOES-R satellite products using simulated data. The GOES-R AQPG Advisory Group is providing feedback to NOAA on GOES-R satellite product features and data delivery systems. Since several of the 3DAQS team members are also part of the GOES-R AQPG, and the 3DAQS End User Group was accustomed to providing feedback on satellite products, it was straightforward to transition the End User Group into the AQPG Advisory Group. In this way, NOAA is benefiting from the groundwork laid by the 3DAQS project in assembling its End User Group, and NASA's investment in 3DAQS is impacting a current operational satellite program at NOAA.

Metric 2: Public Online Survey for Users of the Smog Blog and IDEA
In order to obtain a range of feedback from the air quality community, we designed a public online survey for users of the Smog Blog and IDEA websites. The Smog Blog in particular attracts a wide and extremely varied audience, including parents of asthmatic children who need to know when air quality is poor, university students studying urban air pollution, and amateur astronomers who need to know when air quality conditions are suitable for star-gazing.

To benchmark 3DAQS performance, we issued a public online survey for users of the Smog Blog and IDEA at the beginning and end of the project. The surveys were accessible through a link on the Smog Blog and IDEA websites. The initial public online survey included questions that were similar to the initial End User Group survey, including questions on the use of satellite data, temporal and spatial data resolutions, data format and delivery, and visualization preferences. The final public online survey focused on measuring the usefulness of 3DAQS project products, such as IDEA, the Smog Blog, and satellite data sets, for the user community at large.

A complete record of the final public online survey results is listed in Appendix B. The survey contained 8 questions, all of which were multiple-choice, except for the last question, which requested a written response. The survey ran for 10 weeks in February-April, 2010. 18 Smog Blog/IDEA users provided answers to the survey. The relatively low turnout compared to the popularity of the site is likely due to users' time constraints and reluctance to engage in surveys. The majority of these users who responded – 67% – visit the Smog Blog/IDEA on a daily basis, which suggests that the enhancements to these sites made under 3DAQS have increased their popularity and usefulness. 50% of the survey respondents visit the websites for assistance with air quality forecasting, and 28% visit because of an interest in their personal health related to air quality conditions. This last response is a change from the initial survey, in which none of the respondents indicated that they visited the Smog Blog/IDEA because they were interested in their personal health. The survey respondents were split fairly evenly on the features of IDEA that they find most useful, with the most popular feature being the 48-hour aerosol trajectory forecast. On the Smog Blog, the daily national air quality discussion and interpretation of satellite imagery are considered the most useful features by 72% and 67% of the respondents, respectively. Similar to the End User Group, the public online respondents cited fire/smoke products as the satellite products that they use the most, followed closely by AOD. Overall, despite the small sample size, the public online survey results suggest that 3DAQS has had an effect on the way the community is using satellite data for air quality analysis.

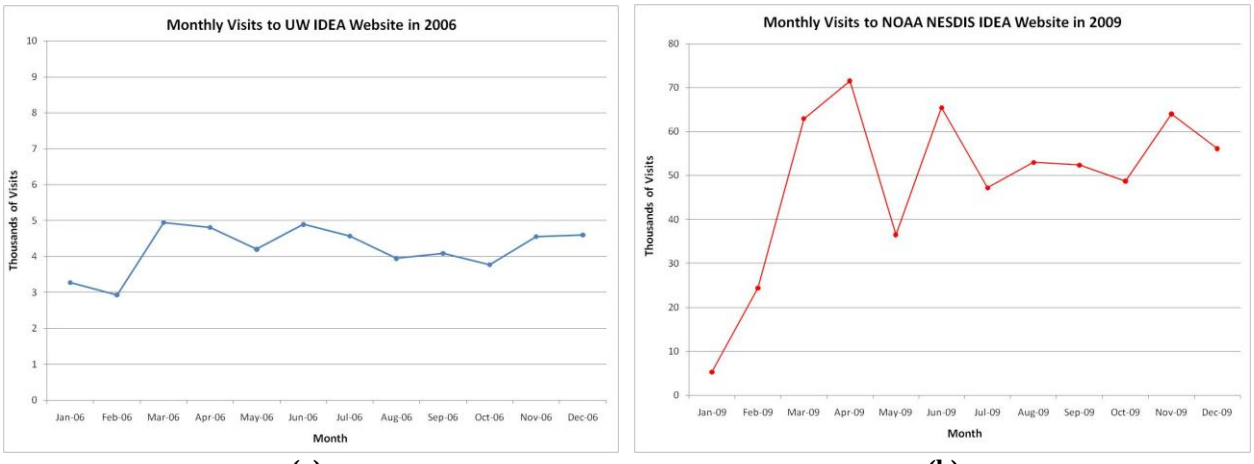
Metric 3: Smog Blog and IDEA Website User Logs
One of the tasks of the 3DAQS project was to transition the IDEA website to an operational environment at NOAA NESDIS. In support of this transition, Al Powell, Director of the NOAA Center for Satellite Applications and Research (STAR), wrote a letter of commitment to Teresa Fryberger, Director of the NASA Applied Sciences Program, in 2007; a copy of the letter is provided in Appendix C.

In order to track the success of the transition, the 3DAQS team recorded user log information for IDEA during the course of the project. The 3DAQS team also recorded user log information for the Smog Blog in order to gauge its impact on the user community.

Table 3 lists the parameters that were measured for the two websites. Analysis focuses on the number of visits to IDEA and the Smog Blog per month as a measure of their popularity and usefulness for the air quality community. 2006 is the baseline year, since this was the first full year of 3DAQS. 2009 is the reference year, since it was the last full year of the project. Figure 1 shows plots of monthly visits to IDEA for 2006 and 2009. In 2006, when IDEA was hosted at the University of Wisconsin (UW), there were approximately 3,000-5,000 visits to IDEA per month. The transition of IDEA from UW to NOAA NESDIS was completed in August 2007, and by Spring 2009, IDEA was experiencing 35,000-70,000 visits per month, which represents an approximately 10-fold increase in visits compared to 2006. This increase indicates that a significant number of additional users have begun to utilize IDEA now that it is in an operational environment at NOAA NESDIS. In contrast, Figure 2 shows that monthly visits to the Smog Blog have remained relatively constant at 25,000-40,000 during the course of 3DAQS, with occasional spikes corresponding to large wildfires (i.e., October 2009), which highlights the established reputation of the Smog Blog in the user community.

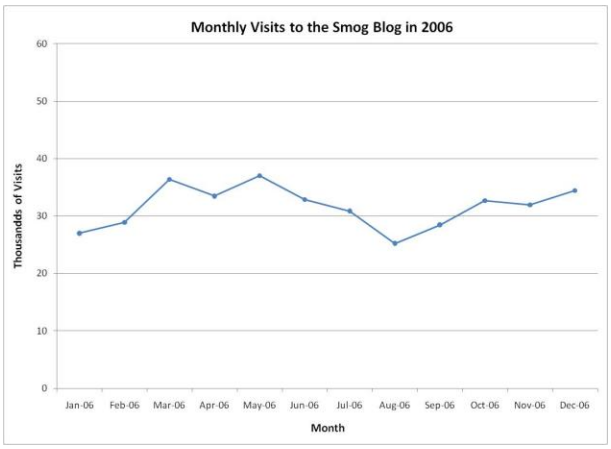
Parameter	Description
Hits	Number of files requested from server
Kilobytes	Data transferred from server to users
Visits	Number of individual users
Pages	Number of web pages viewed
U.S. Educational Users	.edu IP addresses
U.S. Government Users	.gov IP addresses
Network Users	.net IP addresses
U.S. Commercial Users	.com IP addresses
U.S. Users	.us IP addresses
Unresolved/Unknown Users	Unknown IP addresses

Table 3. Smog Blog and IDEA Website User Log Parameters.

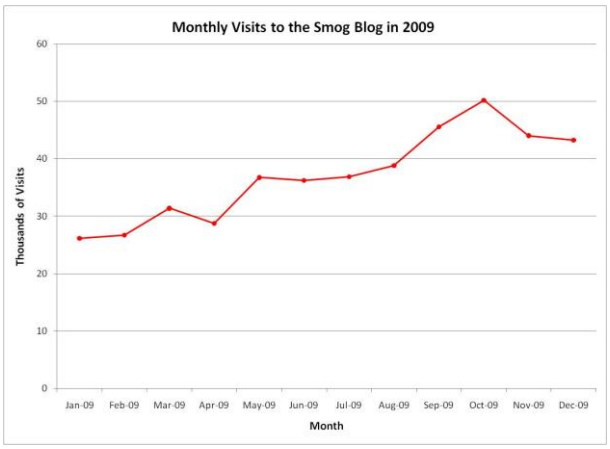


(a) **(b)**

Figure 1. Monthly Visits to the IDEA Website in (a) 2006 and (b) 2009.



(a)



(b)

Figure 2. Monthly Visits to the Smog Blog in (a) 2006 and (b) 2009.

Metric 4: Satellite Data Accessibility

One of the main goals of the 3DAQS project was to improve the availability and accessibility of air quality satellite data for the user community. There were two tasks by which the project aimed to achieve this goal.

1. Transition of IDEA to an Operational Environment at NOAA NESDIS

As stated in the discussion of Metric 3, IDEA was successfully transitioned from an experimental system, hosted by UW, to an operational environment at NOAA NESDIS in August 2007. During this process, Steve Ackerman and Tony Wimmers of UW provided support on transitioning the code to UMBC and then to NOAA, while Jay Al-Saadi and Chieko Kittaka of NASA LaRC provided historical information on the code development and trajectory model background. UW stopped supporting their experimental IDEA site on September 30, 2007, although they kept it running for several months after that date with minimal maintenance to help facilitate the transition to NOAA NESDIS. UMBC maintains an IDEA development site (http://idea.umbc.edu/), which is supported by funding from NOAA NESDIS. UW has continued to collaborate on tools to support IDEA and the Smog Blog, notably the development of the IDEA RGB/AOD slider bar and the MODIS Today KML data. UW also provided KML code to UMBC to help develop MODIS AOD files in KML format, which are now available on the NESDIS IDEA site. Currently, NESDIS maintains IDEA as "pre-operational," which means that it is supported Monday-Friday, 8 AM – 5 PM.

2. Integration of 3DAQS Datasets into EPA's Decision Support Framework

At the inception of 3DAQS, EPA identified its AirQuest system as a permanent repository for the satellite datasets that would be re-gridded and matched to ground-based monitors as part of the project. In November 2007, the 3DAQS team conducted a preliminary benchmarking meeting at EPA's Research Triangle Park campus to demonstrate AirQuest's capabilities using remote sensing data from the 3DAQS project. As part of AirQuest, EPA provided and maintained a password-protected web tool for 2007-8 that allowed users outside of the EPA firewall to download AOD data by date and U.S. PM monitoring station(s). As the project

progressed, however, the 3DAQS team determined that AirQuest could not accept some 3DAQS data, such as UMBC lidar data and AOD data that had been re-gridded onto the 12 × 12 km^2 Community Multi-scale Air Quality (CMAQ) model grid. As a result of these limitations, EPA reevaluated AirQuest as the ultimate repository for 3DAQS data, and in approximately February 2009, EPA decided to discontinue support of AirQuest. Consequently, the 3DAQS datasets that have been incorporated into AirQuest are not accessible to the general air quality community. Instead, they are available via an ftp download from the 3DAQS website (http://alg.umbc.edu/3d-aqs/) and EPA's RSIG system, described in detail below.

Table 4 lists the data sets that were developed as part of the 3DAQS project. The 3DAQS datasets were prepared for 2004-2008. For users who require data after 2008, RSIG will automatically re-grid or match satellite data to the ground-based monitor network.

Data sets delivered to RSIG and AirQuest (2004-2008)	MODIS AOD matched to $PM_{2.5}$ monitors
	GASP AOD matched to $PM_{2.5}$ monitors
	MISR AOD matched to $PM_{2.5}$ monitors
	OMI NO_2 (GSFC "Standard Product") matched to NO_2 monitors
Data sets delivered to RSIG (2004-2008)	MODIS AOD gridded to 12×12 km^2 CMAQ grid
	GASP AOD gridded to 12×12 km^2 CMAQ grid
	Ground-based lidar, averaged hourly with 15 m average vertical profiles
	CALIPSO gridded to $PM_{2.5}$ monitors and 12×12 km^2 CMAQ grid (pending release of CALIPSO V.3 data)

Table 4. 3DAQS Datasets.

While RSIG was not part of the original 3DAQS proposal, this re-direction of the project and investment by EPA are significant achievements. The investment by EPA in RSIG represents implicit acknowledgement of the value of Earth satellite observations, and it demonstrates successful sustained use by a partner organization.

Overview of the RSIG System

RSIG was initially a prototype system developed under the EPA-GEO Advance Monitoring Initiative (AMI), and its goal was to demonstrate the ability to share and integrate Earth observation data with partners at NASA and NOAA using a distributed architecture. In FY08, EPA decided to develop the RSIG system to leverage the investments in the 3DAQS project. As a result, EPA extended the timeline for the final completion of the RSIG project to the end of FY10.

In March 2010, with support from the CALIPSO Science Team and Atmospheric Science Data Center at NASA LaRC, EPA completed a direct connection to the CALIPSO Level 1b aerosol dataset, which marked the creation of an operational 3D-Air Quality System and fulfilled a major commitment to the 3DAQS project and the broader air quality community. EPA's Remote Sensing Information Gateway is now an operational web-based tool (www.epa.gov/rsig) that enables users to access a variety of distributed air quality datasets in a highly efficient manner,

including MODIS, GASP, and CALIPSO data. Figure 3 is a graphical overview of RSIG's datasets and products. The RSIG architecture was designed to operate as a virtual server that connects users to data at point of primary origin versus copying data into large databases to reproduce what already exist and are supported elsewhere.

Key features offered by RSIG include:

- **Ease of use.** RSIG provides a single website that serves as a selective access point to many kinds of data.
- **Selectivity.** RSIG accesses large numbers of files from diverse sources and streams the user-selected subset of data back to the user's desktop. In this way, the data travel directly to the client computer's memory and are discarded unless the user saves the data to a file.
- **Simplicity.** RSIG aggregates multiple files of a given data type into a single entity, reducing the download burden and simplifying data analysis.
- **Built-in data visualization.** RSIG can immediately integrate multiple selected datasets into a single MPEG animation. For example, EPA AIRNow data can be layered over NASA's MODIS satellite data, or a user can compare CMAQ predicted outputs alongside actual ground sensor data. The user can also save the animation or individual images to his PC.
- **Standard data formats.** RSIG integrates incoming proprietary dataset formats into standard formats the user can save to his PC. A user can save the data or visualization – or both – to his local computer in such standard formats as portable binary, ASCII, NetCDF, and MPEG. The user can then export the selected datasets from RSIG into other applications, such as GIS tools, for further analysis.
- **Speed.** RSIG accomplishes all of these tasks far faster than a lone user could with currently-available means. For example, RSIG can capture a week's worth of MODIS AOD data in a few minutes, compared to up to two months using conventional methods.

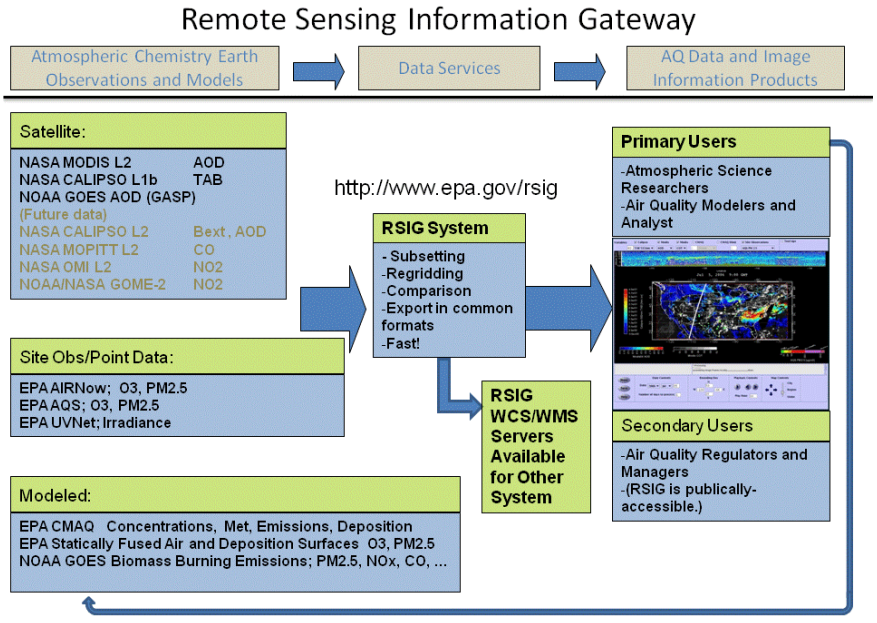


Figure 3. Graphical Overview of the RSIG System.

Most users will utilize a web browser to run the RSIG applet, which features menus, buttons, and a map of the world from which the user can select areas of interest, animate results, and save subsets of data. Figure 4 shows a screen shot example of the RSIG applet. In addition to the applet, RSIG employs the Open Geospatial Consortium (OGC) Web Coverage Services (WCS) and Web Mapping Services (WMS) web-server interfaces. RSIG's graphical user interface (GUI) invokes the WMS and WCS web servers directly to obtain data and obtain visualization images.

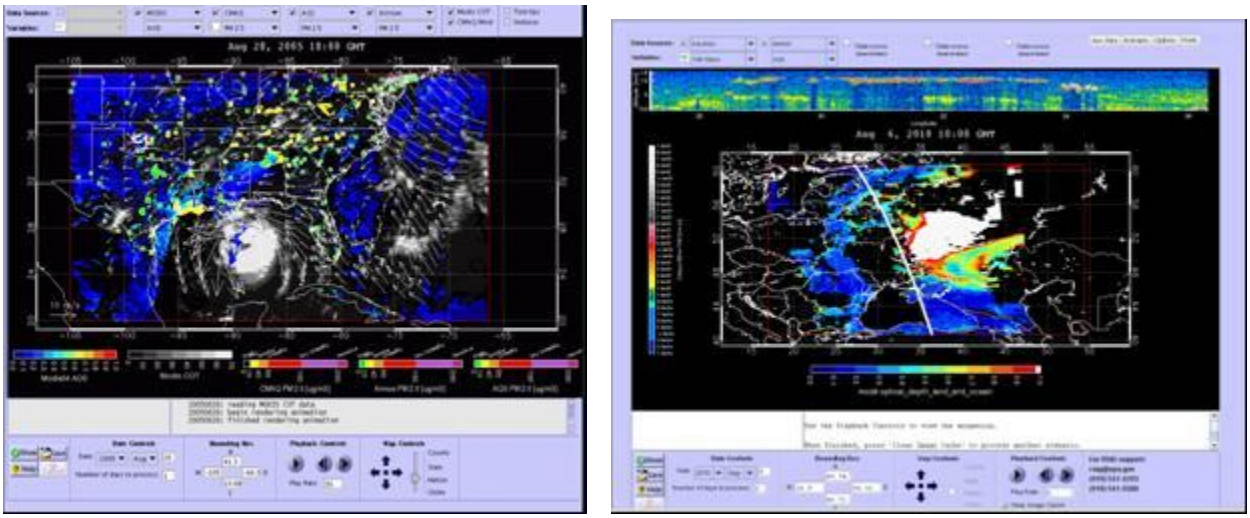


Figure 4. Screenshots of RSIG's Applet. In this example, RSIG overlays CALISPO 532 TAB and MODIS AOD datasets into a single visualization that the user can save as an animation or as individual image files.

Figure 5 shows the overall architecture of the RSIG system. OGC-WCS/WMS server scripts for access to the MODIS and CALIPSO data were designed by EPA and deployed on remote servers at NASA GSFC and NASA LaRC to provide direct access to data products. Currently, access to the NOAA GASP data product is provided via a WCS script that accesses the GASP files on a server at EPA's National Computer Center (NCC). Efforts are currently ongoing to deploy the scripts to NOAA NESDIS for a configuration consistent with access to MODIS and CALIPSO data. As a result of the distributed architecture approach, users are able to access the most recent version of the satellite data products, so improvements from new algorithms are immediately realized by the RSIG user.

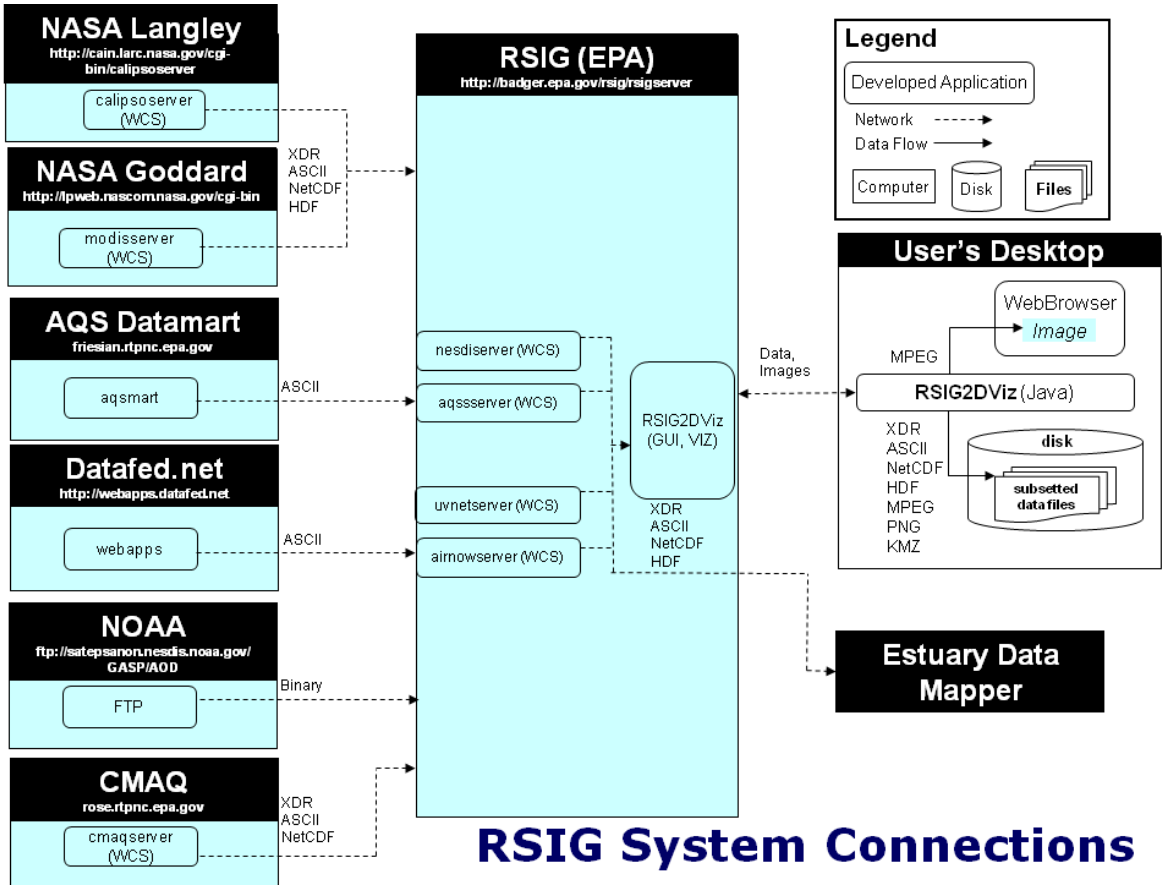


Figure 5. RSIG System Connections.

Table 5 lists file counts and the data volumes of current and future data products available via RSIG. As a result of the distributed architecture, EPA expects to save over 200 TB of active disk storage associated with the satellite data products. RSIG was developed to coordinate with standards of other EPA systems and partners, and it currently works with systems from other entities, such as NASA. However, it should be noted that standards are imperfectly implemented among data providers, and RSIG compensates for these differences. RSIG employs dozens of appropriate data standards, most importantly OGC-WCS/WMS in its publicly-accessible "rsigserver" application. This application serves RSIG data and images to any external application in a variety of standard formats, such as NetCDF, Cooperative Ocean/Atmosphere Research Data Service (COARDS), NetCDF Input/Output Applications Programming Interface (IO/API) (the native format used by CMAQ), zipped Keyhole Markup Language (KMZ), Hierarchical Data File (HDF), IEEE-754, International System of Units (SI), binary eXternal Data Representation (XDR), MPEG animations, PNG image format, and tab-delimited ASCII file. Developers who wish to access environmental data via RSIG can use the WCS/WMS-compliant server scripts. The RSIG internal web site contains several examples of UNIX commands that employ wget (a free UNIX utility) to run the script.

Product	Release version	File count	Avg. file size (MB)	Total size (TB)
MODIS (terra/aqua) 2000 to 2009				
MOD04_L2	5	467350	2.5	**1.17**
MYD04_L2	5	348010	2.5	**0.87**
MOD06_L2		1035360	60	**62.12**
MYD06_L2		770976	60	**46.26**
GOES AOD				
GASP_east				**0.00**
GASP_west				**0.00**
CMAQ				
CMAQ EPA/OAQPS 2002 eastern domain				**5.50**
CMAQ EPA/OAQPS 2002 western domain				**3.40**
CALIPSO				
CAL_LID_L1	3.01	32682	457	**14.94**
Future datasets				
CMAQ 01-06 EPA/CDC 12km eastern domain				**75.00**
CMAQ 01-06 EPA/CDC 36km CONUS domain				**0.00**
CMAQ 06 EPA/AMAD/AQMEII				**18.00**
CALIPSO				
CAL_LID_L2_01kmCLay	3.01	8261	33	**0.27**
CAL_LID_L2_05kmALay	3.01	8260	17	**0.14**
CAL_LID_L2_05kmCLay	3.01	8261	17	**0.14**
CAL_LID_L2_333mCLay	3.01	8261	51	**0.42**
CAL_LID_L2_VFM	3.01	8261	43	**0.36**
MOPITT				
MOP02	4.00	2830	130	**0.37**
GOME-2*				
GOME NO2 Granule files: GOME_M02_NO2 GOME NO2 Daily Level 3 files: GOME_M02_NO2TROP GOME_M02_NO2VCD		365	160000	**58.4**
Total Volume				**282**

Table 5. Current and Future Disk Storage Needs for RSIG/3D-AQS.

Long-Term Aspects of the EPA DSS in Air Quality Decision-Making

Scheffe et al. (2009) recently outlined the need for an integrated air quality management framework that includes observational and model data, with the goal of addressing the critical issues facing regional and local air quality planning. This approach, represented in Figure 6, recognizes the need to develop the full capabilities and strengths of the various observational data platforms in order to create a coordinated suite of 3-D measurements of pollutants, including column abundances, vertical atmospheric profiles, and surface mass concentrations or

mixing ratios. Maintaining healthy air quality is one of the primary missions of EPA. The results of the RSIG/3DAQS effort will allow EPA to routinely access key satellite aerosol data sets for evaluation of aerosol predictions from air quality models, such as CMAQ. This approach will ultimately result in enhanced scientific credibility for policy decisions by EPA, state and local air quality agencies, and the international community.

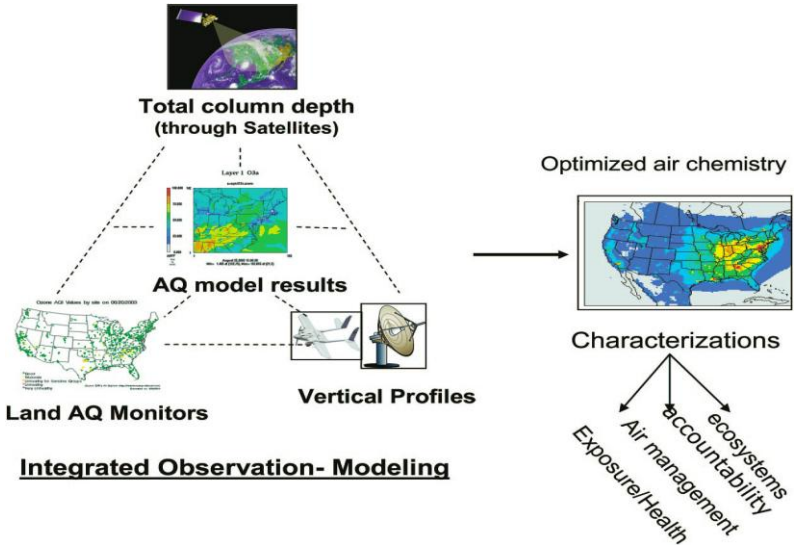


Figure 6. Overview of an Integrated Air Quality Management Framework [Scheffe et al., 2009].

Metric 5: Improved Air Quality Forecast Performance

This metric was designed to measure quantitatively the value that re-gridded satellite data, provided by the 3DAQS project, bring to the user community. One of the members of the 3DAQS End User Group, Gopal Sistla, Director of the New York State Department of Environmental Conservation (NYSDEC) Bureau of Air Quality Analysis and Research, generates air-quality forecasts based on the CMAQ model for use by NYS air quality forecasters. At the inception of the 3DAQS project, Dr. Sistla and his colleague, Prakash Doraiswamy, intended to incorporate MODIS AOD data into their air quality model during the 2006-2009 time period. Consequently, the original aim of Metric 5 was to measure the change in accuracy and bias of the NYSDEC air quality model after incorporation of AOD, with the expectation that the satellite data would improve model performance. Due to time limitations independent of the 3DAQS project, Dr. Doraiswamy has not yet had the opportunity to incorporate AOD into the model. As a result, evaluation of Metric 5 as originally envisioned is not possible. The NYSDEC team has used 3DAQS AOD data to evaluate the performance of their model, however, and the 3DAQS team used these results to benchmark the project under a revised version of Metric 5.

Dr. Doraiswamy recently conducted a study in which he determined the utility of using AOD data to evaluate the NYSDEC air quality model. He presented his results at the 109th Air and

Waste Management Association (AWMA) Annual Meeting in June 2009 (Doraiswamy et al., 2009). In his study, Dr. Doraiswamy compared ground-level $PM_{2.5}$ concentrations predicted by the NYSDEC model to Terra MODIS AOD at 20 sites in New York State. He used AOD data for the 1-year period from June 2005 to May 2006 that had been re-gridded to the 12×12 km^2 CMAQ grid as part of the 3DAQS project. Results showed that the AOD data were useful for model evaluation, particularly in situations where there were significant aerosol concentrations above the boundary layer. For example, in one case study, the model seemed to under-predict $PM_{2.5}$ concentrations in the upper layers of the atmosphere. The cause of the under-prediction was likely due to transported smoke from wildfires and inter-continental dust, neither of which are accounted for in the model simulations. Dr. Doraiswamy concluded that since satellite data can help detect aerosol transport events, they can be used to adjust model forecasts. The NYSDEC study demonstrates the usefulness of satellite data for the evaluation of air quality modeling, and illustrates how the 3DAQS project's data re-gridding and accessibility tasks have benefited one aspect of the user community.

Additional Project Metrics

There are several additional measures of success that demonstrate the utility of the 3DAQS project but were not formally included as metrics in the original Benchmarking report.

Several of the journal publications which occurred over the course of the 3DAQS project will provide lasting impact on the air quality community. In particular, the PM-AOD correlation work of Engel-Cox et al. (2005a, 2005b, 2006) at the beginning of the project was enhanced in papers by Zhang et al. (2009) and Weber et al. (2010). Hoff and the 3DAQS team published a discussion of the use of 3DAQS data for western air quality (2009b), and the overview paper of Hoff and Christopher (2009a) provided a serious look at the questions involved in using satellite data for compliance, monitoring and assessment. While challenges arose to the use of such data for compliance (Hidy et al., 2010), it is clear that satellite data are now routinely accessed through tools such as IDEA, the Smog Blog, and, in the future, RSIG.

The numerous presentations by 3DAQS team members on NASA and NOAA data products at national and international conferences have increased interest in these data. In addition, members of the 3DAQS team conducted two training courses on use of project data for air quality forecasting and analysis at the 2008 and 2009 National Air Quality Conferences. These training efforts have evolved into a formal NASA training program that feeds into the NASA SERVIR program (http://www.servir.net/) and other national and international training courses. 3DAQS team member Ana Prados of UMBC has used her early work in the 3DAQS project for development of the current suite of NASA training modules.

In an effort to improve the accuracy of $PM_{2.5}$ concentration datasets used in health studies, the 3DAQS team also conducted a pilot study in which they applied a statistical hierarchical Bayesian model to MODIS AOD data for the metropolitan Baltimore, Maryland region. Working with Dr. John Braggio of the Maryland Department of Health and Mental Hygiene and Fred Dimmick of EPA, results from the pilot study indicated that Bayesian infilling of MODIS AOD data between ground monitors increased predictive skill for Emergency Department asthma visits and hospitalizations for myocardial infarctions in Baltimore in 2005 compared to

ground-based $PM_{2.5}$ data or AOD data alone (Huff et al., 2010). This work is still in an early stage but members of the 3DAQS team will be pursuing it in the future in other projects.

Acknowledgements
The authors thank 3DAQS co-investigators Jill Engel-Cox, Tony Wimmers, Steve Ackerman, Jay Al-Saadi, Cheiko Kittaka, Shobha Kondragunta, Fred Dimmick, Brad Johns, and Ana Prados for their invaluable contributions to the project.

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Appendix A: End User Group Survey Results (Metric 1) – 10 total respondents

Question	Answer	Count	Percentage
For what type of organization do you work?	Federal government	2	20
	State government	7	70
	Local government	0	0
	Non-governmental organization	0	0
	University or research organization	1	10
	Industry/private sector	0	0
	Other (please indicate)	0	0
How often do you use satellite data or imagery for air quality applications?	Daily	5	50
	Weekly	2	20
	Monthly	1	10
	Only during major pollution events	1	10
For what applications do you use satellite products? (select all that apply)	Air quality forecasting	7	70
	Air quality modeling	1	10
	Retrospective or historical analysis	8	80
	Climate assessment	1	10
	Environmental policy or program assessment	1	10
	Academic research	4	40
	Other (please specify)	0	
What types of satellite products do you use routinely? (select all that apply)	MODIS true color imagery	5	50
	MODIS AOD	7	70
	GASP AOD	6	60
	Fire/smoke products	8	80
	OMI NO_2	3	30
	OMI SO_2	1	10
	CALIPSO	2	20
	NAAPS aerosol forecasts	3	30
	Other (please indicate)	0	0
Do you rely on prepared satellite imagery of do you download satellite data for your applications?	Prepared satellite imagery	7	70
	Download data for my specific applications	1	10
	Both	1	10
What 3DAQS products do you use/ have you used for your work? (select all that apply)	IDEA	7	70
	U.S. Air Quality Smog Blog	9	90
	AirQuest	2	20
	Remote Sensing Information Gateway (RSIG)	1	10
	Re-gridded MODIS AOD, GASP AOD, MISR AOD, and/or OMI NO_2 datasets	4	40
	UMBC REALM ground-based LIDAR data	4	40
	Satellite training sessions at the 2008 and 2009 National Air Quality Conferences	3	30
For users of IDEA: Which improvements to	Overlays of MODIS true color and	3	30

Question	Answer	Count	Percentage
IDEA made during the course of the 3DAQS project facilitated your use of satellite products?	AOD		
	"Slider bar" between MODIS true color and AOD	2	20
	Loops of GASP and GASP West AOD	3	30
	48-hour aerosol trajectory forecast	5	50
	Estimation of $PM_{2.5}$ concentration from AOD values	3	30
	National correlation map between surface $PM_{2.5}$ and MODIS AOD	3	30
	Time-series and correlations of MODIS/GASP AOD and surface $PM_{2.5}$	4	40
For users of the Smog Blog: What features of the Smog Blog are most useful for your work?	Daily national air quality discussion	6	60
	Daily interpretation of air quality satellite imagery	5	50
	List of links to air quality satellite, ground-based, and model products	4	40
	Help files	2	20
	Archive of daily air quality discussions (9/03-present)	7	70
	Comments	0	0
One of the goals of the 3DAQS project was to make re-gridded satellite data available to the user community via EPA's AirQuest database. However, EPA has discontinued support of AirQuest, so the re-gridded data are available as an ftp download from the 3DAQS website instead. Would you be more likely to use the re-gridded datasets if they were maintained in a national database, such as AirQuest or RSIG?	Data should be maintained on a government-run site	2	20
	Data should be maintained on the 3DAQS website	0	0
	It doesn't matter to me where the data are located	8	80
For participants in the satellite training sessions at the 2008 and 2009 National Air Quality Conferences: Did the training sessions result in an increased use of satellite products in your work?	Yes	2	20
	No	1	10
	Did not attend training	7	70
Do you use kml or kmz files in Google Earth to visualize air quality data? Please indicate which types of data you visualize.	MODIS true color imagery	4	40
	AIRNow AQI values	3	30
	NOAA Hazard Mapping System fire and smoke locations	4	40
	USDA MODIS current fire locations and information	3	30
	FIRMS global MODIS active fires and hotspots	0	0
	CALIPSO vertical aerosol profiles	1	10
	NAAPS aerosol forecast	2	20

Question	Answer	Count	Percentage
	NWS weather data	4	40
	HYSPLIT airmass trajectories	3	30
	I do not use Google Earth	5	50
Has the 3DAQS project changed the overall way you use satellite products in your work? Please explain how the project has or has not helped you.	Yes, the IDEA site coupled with the smog blog has increased my awareness of events and available data on these events that I log and retrieve later when doing retrospective analysis or proposal development.		
	It's made things much easier for me when analyzing real-time and case-study data.		
	The 3DAQS project has enhanced my desire and ability to utilize satellite products in my air quality forecasting. It has exposed me to a broader range of resources to make my forecast. The smog blog is very beneficial to me, as I'm able to see (on a national and local scale) the air quality conditions. The satellite and air quality images provided in the blog are also of great resource.		
	I have been an active user of the Smog Blog for a few years now and have found the daily interpretation of air quality satellite imagery has enhanced my understanding of satellite imagery as it relates to air quality. In addition, this site was my first introduction to lidar imagery and I found interpretation of this type of data to be very interesting. Not initially serving on the 3DAQS End User Group up until very recently, I cannot speak to many improvements that I have noticed on IDEA. I do, however, find many of the products very useful.		
	Somewhat. Satellite products are utilized more for post analysis of air quality events.		
	Yes. It introduced us to the new products available from satellite-based observations, and how it may be of use to us. While the limitation that we face currently is easy access of data in a format that we would like, it has definitely enhanced our understanding and perception of the products available, the data produced and its limitations. The "smog-blog" website serves as an archive of air quality events and their interpretation, and helps us in looking back at some retrospective events or model evaluation exercises.		
	The Smog Blog archive is very useful for post analysis of forecasts and I also use it for classroom work. The Smog Blog daily discussion is useful for getting oriented first thing in the morning as it summarizes the previous day and also keeps an eye on the smoke issues. Overall, 3DAQS has been most helpful with smoke issues; also very helpful with post-analysis of forecasts.		
	Unfortunately, I was not able to participate much in this project but it wasn't due to lack of interest. I definitely see uses for this kind of data/information in AQ planning – and with more interest in accountability, to make the connections between AQ and health impacts through epidemiology studies. Epi studies require a spatial field (matched to monitors and to CMAQ grid). Right now, they are limited to getting these spatial fields from interpolated monitoring data, modeling data, or Bayesian		

Question	Answer	Count	Percentage
	hierarchical combined monitoring/modeling spatial fields. It'd be great to have another source of spatial data. Having the 3DAQS project has enabled me to see some new possibilities. Please continue this valuable work. Part of the problem in engaging in this office is that we lack the expertise to utilize this information. The modelers are generally engaged in regulatory activity and it is difficult to find the right combination of expertise, time and interest.		

Appendix B: Online Survey Results (Metric 2) – 18 total respondents

Question	Answer	Count	Percentage
For what type of organization do you work?	Federal government	1	6
	State government	5	28
	Local government	2	11
	Non-governmental organization	0	0
	University or research organization	3	17
	Industry/private sector	0	0
	Individual (personal interest)	2	11
	Other	5	28
How often do you visit IDEA and/or the Smog Blog for air quality satellite information?	Daily	12	67
	Weekly	3	17
	Monthly	1	6
	Only during major pollution events	2	11
What is your primary reason for visiting IDEA and/or the Smog Blog to obtain air quality satellite information? (select all that apply)	Air quality forecasting	9	50
	Air quality modeling	1	6
	Retrospective or historical analysis	1	6
	Environmental policy or program assessment	0	0
	Academic research	2	11
	Visibility information	0	0
	Weather information	0	0
	Personal health interest	5	28
	Other	0	0
What features of IDEA do you find most useful?	MODIS and GASP AOD imagery	9	50
	MODIS true color imagery	8	44
	48-hour aerosol trajectory forecast	11	61
	3-day composite history of MODIS AOD and ground-based monitor $PM_{2.5}$ measurements	7	39
	Estimation of $PM_{2.5}$ concentration from AOD values	6	33
	National correlation map between surface $PM_{2.5}$ and MODIS AOD	5	28
	Time-series and correlations of MODIS/GASP AOD and surface $PM_{2.5}$	6	33
	Tutorials for interpreting the IDEA products	4	22
	I do not use IDEA	3	17
What features of the Smog Blog do you find most useful? (select all that apply)	Daily national air quality discussion	12	67
	Daily interpretation of air quality satellite imagery	13	72
	List of links to air quality satellite, ground-based, and model products	9	50
	Help files	0	0
	Archive of daily air quality discussions (9/03-present)	7	39
	Comments	1	6
	I do not use the Smog Blog	0	0

Question	Answer	Count	Percentage
If you use satellite data or imagery on a regular basis, what types of products do you use? (select all that apply)	True color images	8	44
	AOD	8	44
	Fire/smoke products	10	56
	OMI NO_2	3	17
	OMI SO_2	1	6
	CALIPSO or ground-based lidar	5	28
	NAAPS aerosol forecasts	4	22
	Other	2	11
	I do not use satellite data or imagery on a regular basis	3	17
What are the main factors that limit you use or understanding of satellite air quality data and imagery? (select all that apply)	Need to know more about relation to ground-based monitoring sites	7	39
	Need to know more about vertical distribution of pollutants	9	50
	Inadequate spatial resolution	6	33
	Inadequate temporal resolution	7	39
	Need customizable imagery	6	33
	Need different data file type(s)	1	6
	Lack of software/technical capability to work with datasets	2	11
	Lack of time/resources/management support	3	17
	Other	2	11
	There are no factors that limit my use or understanding of satellite products	2	11
What additional products or features would you like IDEA and/or the Smog Blog to provide?	A forum web board where readers and your lab people can communicate?		
	Personally I would like to see more information about the technology being used for this high tech tools. I think our BAM PM monitors are fairly cool, but there are a lot better tools in the NASA/NOAA tool box.		
	IDEA could develop another product like the AOD/trajectory product by combining a loop of IR imagery and adding the 700 hPa modeled relative humidity fields. An example of this product would be a 3-hour loop of GOES IR imagery then hold a static image of the most recent IR image and overlay it with GFS or NAM relative humidity values shaded with gradients of 70-90% and 90-100%. Meteorologists use relative humidity at 700 hPa to estimate cloud cover. The previous 3-hour loop would provide as a reference to show how closely the modeled results resemble reality. A product like this could provide guidance to an air quality forecaster concerned with ground-level ozone which very much depends on predicted cloud cover		
	Local $PM_{2.5}$ & O_3 predictions / animations. Sulfate and other pollution predictions / animations. Many thanks for your invaluable web site, useful for personal and small-business planning.		

Appendix C: 2007 Letter of Commitment from NOAA to NASA re: IDEA

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL ENVIRONMENTAL SATELLITE, DATA AND INFORMATION SERVICE
Silver Spring, Maryland 20910

June 8, 2007

Dr. Teresa Fryberger
Associate Director for Applied Sciences
Earth Science Division
Science Mission Directorate
NASA Headquarters
Mail Suite: 3B74
Washington, DC 20546

Dear Dr. Fryberger:

I am pleased to send this letter to confirm the commitment of the NOAA, National Environmental Satellite Data and Information Service (NESDIS), Center for Satellite Applications and Research (STAR) to transition the Infusing Satellite Data into Environmental Applications (IDEA) software to NOAA for operational implementation. The IDEA system was jointly developed by NASA, NOAA, and the EPA to assist with the forecast of long-range transport of aerosol plumes that can impact local air quality. It currently uses NASA Terra MODIS Aerosol Optical Depth (AOD), NASA/NOAA observations of fire locations, EPA surface observations of PM2.5, and a NASA trajectory model to provide forecast guidance for fine particulate matter. The EPA has requested NOAA/NESDIS to transition this product or something similar into an operational setting at NESDIS. Operational implementation will ensure the availability of product without interruptions associated with technical failures.

The IDEA system currently running in near real time at the University of Wisconsin – Madison is widely accessed by air quality community for various applications. Users include state and local air quality forecasters, managers, and policy makers. The increase in IDEA based air quality forecast discussion on smog blogs (e.g., http://alg.umbc.edu/usaq/) and other air quality forums has been phenomenal and warrants continued support. While the development and implementation of IDEA has been a multi-agency effort with NASA providing seed money to kick-start the project, the responsibility to transition this system into operations lies with NOAA. NOAA, NESDIS is already processing MODIS data in near real time and will leverage those resources for operational implementation of the IDEA system.

NESDIS is currently engaged in supporting the NWS and the EPA in meeting their air quality forecasting and monitoring mandates. AOD product from NOAA's geostationary remote sensing sensors will complement the global views of MODIS sensor by providing rapid refresh rates. NESDIS/STAR is working towards adapting the IDEA system and modifying it with GOES aerosol products for operational implementation at NESDIS. In

fiscal year 2007, work has begun to transition the IDEA system for implementation in a pre-operational mode on NESDIS computers and test out the logistics of accessing all the various inputs needed in timely fashion. While the IDEA system is being tested, off-line research work will be carried out to prepare the IDEA system to accept rapid updates of AOD measurements from GOES satellites. After the checkout phase in preoperational mode at NESDIS/STAR and the approval of NESDIS Satellite Product Services Review Board (SPSRB), the original IDEA system will move to operational status in 2008 at NESDIS Office of Satellite Data Product Distribution (OSDPD). The modified IDEA system with GOES AOD product will become operational at a later date when the product is ready and approved by SPSRB.

NASA and NOAA have collaborated successfully with POES and GOES systems. The transition of NASA research algorithms, software and analysis tools to derive environmental products for operational implementation at NOAA has been an ongoing effort. The transition of IDEA system to NESDIS will extend that cooperation. I like to take this opportunity to congratulate NASA for its leadership. As resources permit, I agree to support and commit the personnel, equipment, and facilities needed to successfully carry out the transition of IDEA system from research to operations.

Sincerely,

Alfred M. Powell, Jr.
Director, Center for Satellite Applications
and Research

cc:
S. Alan Stern, NASA Science Mission Directorate
Michael Freilich, NASA SMD Earth Science Division
Jack Kaye, NASA SMD ESD Research Program
Martin Frederick, NASA SMD ESD Applied Sciences Program
Lawrence Friedl, NASA SMD ESD Applied Sciences Program
Lelia Vann, NASA Langley Research Center
Franco Einaudi, NASA Goddard Space Flight Center